A TESTING PROCEDURE AND METHOD FOR QUALIFYING CAMERAS FOR AUTOMOTIVE USE UNDER HIGH GLARE CONDITIONS

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Abstract

Cameras for automotive use need to provide sufficient contrast resolution under many light conditions. The authors have developed a testing procedure, adapted from detection experiment methodology used for evaluating vehicle camouflage, that checks a camera's ability to perform in situations where there is high light level in some areas and low light level in others. The procedure simulates the situation of looking into oncoming traffic at night and gives a quantitative measure of the resolving ability of the camera as the lighting is varied.

1. Introduction

The use of cameras in automotive applications for safety, comfort and convenience is increasing rapidly. Applications such as blind spot warning, pedestrian recognition, adaptive cruise control and driver recognition all require cameras that work under greatly varying light conditions [1,2]. Cameras for automotive use need to provide sufficient contrast resolution under these conditions.

The most challenging light condition is when a portion of the scene is brightly lit, and another portion is in deep shadow. This situation can occur whenever the sun is in the field of view. In northern locales this occurs most of the day in winter. At night when other vehicles are present, this is a very common situation when another vehicle's headlights are within the field of view.

Camera specifications from the manufacturer typically contain information such as lowest operable light level and resolution. However this information is not usually sufficient to characterize a camera for automotive applications. Most low light cameras perform well when the entire scene is dark, but provide almost no contrast if there is a bright object in the scene. Even if the camera doesn't bloom, this lack of contrast makes the cameras unsuitable for automotive use.

2.Experimental Procedure

The authors have developed a testing procedure that checks a camera's ability to perform in situations where there is high light level in some areas and low light level in others. The procedure simulates the situation of looking into oncoming traffic at night. The test procedure is adapted from detection experiment methodology used for evaluating vehicle camouflage and gives a quantitative measure of the resolving ability of the camera as the lighting is varied. The camera under test is focused on a USAF Tribar of a size that is easily resolvable in normal lighting. A standard 60-watt light bulb is placed in front of a standard size white sheet of paper half way between the target and the camera. Fig. 1 and 2 show the experimental set-up for this test. The distance D (see Fig. 1) from the camera to the target is determined by observing the image on a monitor and adjusting the distance until the target is ¼ the height of the screen and its center is 1/3 of the screen’s width from the right hand edge (see Fig. 2). This method was chosen to make the scene viewed by each camera similar regardless of the camera’s field of view.

Camera performance under varying light conditions was assessed by progressively blocking off the image of the bulb, as seen by the camera, and recording the response from 4 observers as to how detectable the target appeared on a monitor. The detectability levels were as follows:

0. can see nothing
1. can tell something is there
2. can resolve 2 separate groups of something

Presented and published in the Proceedings of the IEEE 2001 Intelligent Vehicles Symposium held at the National Institute of Informatics, Tokyo, Japan.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **13 MAY 2001**	2. REPORT TYPE **N/A**	3. DATES COVERED
4. TITLE AND SUBTITLE **A Testing Procedure and Method for Qualifying Cameras for Automotive Use Under High Glare Conditions**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S) **; ; ; ; ; ; ; Meitzler /ThomasBednarz /DavidSohn /EuijungLane /KimBryk /DarrylEbenstine /SamuelSmith /Greg,HRankin II /James**		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **US Army RDECOM-TARDEC 6501 E 11 Mile Rd Warren, MI 48397-5000**		8. PERFORMING ORGANIZATION REPORT NUMBER **18576**
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) **TACOM TARDEC**		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release, distribution unlimited.**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**SAR**	**6**	

3. can clearly resolve one group of 3 bars
4. can clearly resolve both the horizontal and vertical bars.

The test began with the light bulb fully exposed to the camera. The camera's view of the light bulb was then progressively blocked with a black shield. The observers were asked to assess the detectability of the target for 20, 40, 60, 80 and 100 % blocking of the bulb. Light levels at the camera and the targets were measured for each test with a Photo Research Spectroradiometer.

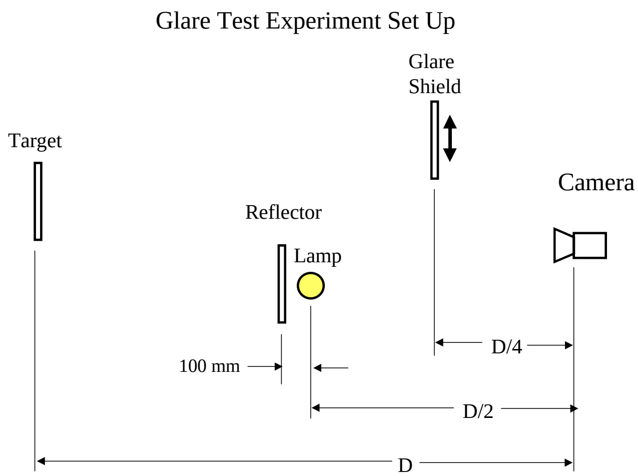

Fig. 1. Experimental Setup to measure detectability of AF 3- bar targets.

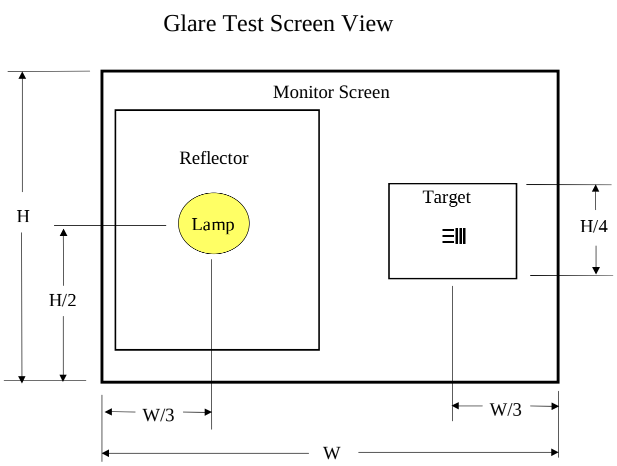

Fig. 2: Position of bar target relative to glare source

Fig. 3: Position of source relative to target in camera FOV

An ANalysis Of VAriance (ANOVA) was then done to determine if there were significant differences between the cameras tested. The results of this analysis are detailed in the next sections.

A second series of tests were performed on three of the original test cameras using two resolution targets illuminated at different light levels. Varying the incident light level in detectability increments created a detailed characterization curve of these cameras. The light level was measured at the target with a photometer. Fig. 4 shows the experimental setup. The targets were displayed in "cubby holes" one meter on a side which allowed dramatically different light levels to be used on the targets. The targets were illuminated by 150-watt spotlights whose brightness could be changed by the use of individual variable transformers. The distance from the tested camera to the target was adjusted to achieve the scene shown on the monitor in Fig. 5. The tests began with both targets illuminated at a level just sufficient to allow resolution of both targets. The light level on the left target was held constant during the experiment while the light on the right target was increased until the resolution degraded. Progressive degradation as the light level at the target was increased was reported by the 4 observers and recorded using the same 0 to 4 scale used in the previous experiments. The light levels at that target were recorded when a transition in detectability was reported by a majority of observers. This test yielded a relationship between detectability and light level as the illumination on the target is increased beyond the optimum level. This relationship is important for automotive applications since it is rarely possible to achieve any control over scene lighting much less achieve optimal conditions. Table 7 summarizes the data from these tests. Figure 13 shows

a representative spectrum of the light incident on the target.

Fig.4: Setup used to measure target luminance

The cameras used in both parts of this experiment are shown below in Table 1. The Sony camera was used with and without a 6 mm lens.

Table 1
Video Cameras Tested

Camera Name	Picture elements	Min. Illumination
ELMO QN42H	786 X 494	20 lux
Panasonic GPKS162	768 X 494	3
Sony DC50A	768 X 494	0.8
Genwac GW-902H	768 X 494	0.0003

Fig. 5: Sample image showing gain problem

3. Data Analysis

From the observer data on the detectability of the five cameras, an Analysis of Variance was done to determine the camera with the highest gain quality and best contrast.

Since the detectability of the bar-targets was measured on an ordinal scale, a rank transformation was performed on the original data. Fig. 6 represents the box-and-whisker plots for the rank of detectability for the five camera types. The following analysis of variance was performed on the transformed data. Table 2 below shows the design of the experiment to rank the cameras. The authors used five cameras, and five shield positions, and four observers. Once a camera is chosen, the subject and the five levels of position are randomly determined. Thus, we have a randomized complete block experiment run in a randomized complete block.

The linear mathematical model for this experiment is given by Equation (1).

$$y_{ijk} = \mu + \tau_i + \beta_j + \delta_k + \varepsilon_{ijk} \quad \begin{cases} i = 1, 2, 3, 4, 5 \\ j = 1, 2, 3, 4 \\ k = 1, 2, 3, 4, 5. \end{cases} \qquad (1)$$

Where, τ_I is the shield position effect, β_j represents the block effect due to the subject, δ_k is the block effect due to the camera, and ε_{ijk} is the normally distributed error term.

The complete analysis of variance is summarized in Table 3. Both CAMERA and POSITION are highly significant. The type of camera used, therefore, does effect the subject's ability to detect the target. A normal probability plot of the standardized residuals is shown in Fig. 7. The assumption that the residuals are normally distributed is verified. Figs. 8 through 11 show the standardized residuals plotted against the fitted values and independent variables. These plots reveal that the assumption of constant variance is satisfied.

Table 2
Between Subjects Factors

Factor	Label	Value	N
Camera	1.0	Sony	20
Type	2.0	Elmo	20
	3.0	Panasonic	20
	5.0	Gemwac	20
	6.0	Sony-6mm	20
Position	0.0	0	20
Of	5.0	5	20
Shield	10.0	10	20
	15.0	15	20
	20.0	20	20
Subject	1		20
	2		20
	3		20
	4		20

Table 3
Between Subject Effects

Dependent Variable: RANK of DETECT

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power[a]
Corrected Model	60034.390[b]	11	5457.672	25.237	.000	277.607	1.000
Intercept	255025.0	1	255025.0	1179.269	.000	1179.269	1.000
CAMERA	5658.325	4	1414.581	6.541	.000	26.165	.989
POSITION	54326.025	4	13581.506	62.803	.000	251.211	1.000
SUBJECT	50.040	3	16.680	.077	.972	.231	.063
Error	19030.610	88	216.257				
Total	334090.0	100					
Corrected Total	79065.000	99					

a. Computed using alpha = .05

b. R Squared = .759 (Adjusted R Squared = .729)

Table 3 shows the significance of the various factors. Subject turned out not to be a statistically significant variable. Table 4 below shows how the cameras ranked relative to each other based on the transformed test means and Table 5 shows the relative significance of each factor and the standard errors, and Table 6 shows the subsets of cameras that were not statistically different.

Table 4

Estimated Mean of Rank of Camera Type

Dependent Variable: RANK of DETECT

camera type	Mean	Std. Error
Sony	61.50000	3.288
Elmo	45.90000	3.288
Panasonic	55.12500	3.288
Gemwac-6mm	50.40000	3.288
Sony-6mm	39.57500	3.288

Table 5
Multiple Comparisons

Dependent Variable: RANK of DETECT
Tukey HSD

(I) camera type	(J) camera type	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Sony	Elmo	15.60000*	4.650	.010	2.64799	28.55201
	Panasonic	6.37500	4.650	.648	-6.57701	19.32701
	Gemwac-6mm	11.10000	4.650	.129	-1.85201	24.05201
	Sony-6mm	21.92500*	4.650	.000	8.97299	34.87701
Elmo	Sony	-15.60000*	4.650	.010	-28.55201	-2.64799
	Panasonic	-9.22500	4.650	.282	-22.17701	3.72701
	Gemwac-6mm	-4.50000	4.650	.869	-17.45201	8.45201
	Sony-6mm	6.32500	4.650	.655	-6.62701	19.27701
Panasonic	Sony	-6.37500	4.650	.648	-19.32701	6.57701
	Elmo	9.22500	4.650	.282	-3.72701	22.17701
	Gemwac-6mm	4.72500	4.650	.847	-8.22701	17.67701
	Sony-6mm	15.55000*	4.650	.010	2.59799	28.50201
Gemwac-6mm	Sony	-11.10000	4.650	.129	-24.05201	1.85201
	Elmo	4.50000	4.650	.869	-8.45201	17.45201
	Panasonic	-4.72500	4.650	.847	-17.67701	8.22701
	Sony-6mm	10.82500	4.650	.146	-2.12701	23.77701
Sony-6mm	Sony	-21.92500*	4.650	.000	-34.87701	-8.97299
	Elmo	-6.32500	4.650	.655	-19.27701	6.62701
	Panasonic	-15.55000*	4.650	.010	-28.50201	-2.59799
	Gemwac-6mm	-10.82500	4.650	.146	-23.77701	2.12701

Based on observed means. The error term is Error.

*. The mean difference is significant at the .05 level.

Table 6
Homogenous Subsets of Detectability Rank

RANK of DETECT

Tukey HSD[a,b]

camera type	N	Subset 1	Subset 2	Subset 3
Sony-6mm	20	39.57500		
Elmo	20	45.90000	45.90000	
Gemwac-6mm	20	50.40000	50.40000	50.40000
Panasonic	20		55.12500	55.12500
Sony	20			61.50000
Sig.		.146	.282	.129

Means for groups in homogeneous subsets are displayed.
Based on Type III Sum of Squares
The error term is Mean Square(Error) = 216.257.

a. Uses Harmonic Mean Sample Size = 20.000.

b. Alpha = .05.

Based on "Tukey's honesty significant difference test", the starred values in Table 5 indicate the pair of means that are significantly different;

C1-C2*

C1-C3
C1-C5
C1-C6*
C2-C3
C2-C5
C2-C6
C3-C5
C3-C6*
C5-C6

Referring to Table 2, C1 is the Sony, C2 is the Elmo, C3 is the Panasonic, C5 is the Gemwac-6mm, and C6 is the Sony-6mm. Based on Tukey's test, the authors conclude that there is not a statistically significant difference in image quality between C1, C3, and C5. These cameras are the best performing of the five tested.

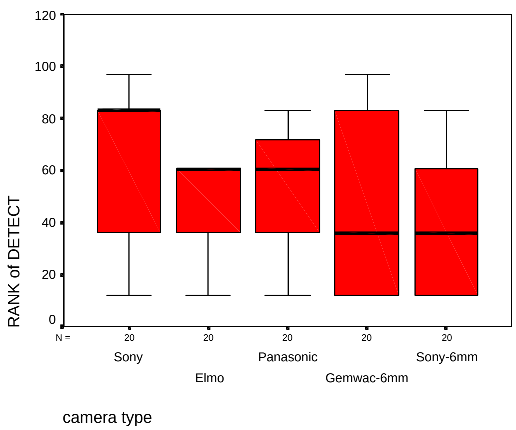

Fig. 6 Box-and-whisker plots for camera types

Fig. 12 is a graph of the data from our second series of experiments and shows the loss of detectability with light increasing on the primary target. These curves are as expected from our original experiments. The left two curves represent the Sony-6mm camera at two slightly different initial values of lighting. They are essentially parallel and are extremely steep. This confirms the perception that near the limits of zero illuminance detectability drops off rapidly. The slope of the curve is directly related to the dynamic range in this region with steeper slopes indicating less dynamic range. The center two curves are for the Elmo camera. Again they are for two slightly different light levels and are parallel and extremely steep with essentially the same shape as the curves for the Sony camera. The rightmost curve is for the Panasonic camera and is distinctly different in shape from the other curves. The distinctly different shape supports the conclusion from the ANOVA multiple comparison in Table 5 of the first set of experiments, which found a significant difference in the data from the Panasonic camera when compared to the Sony-6mm camera and not a significant difference when the Elmo camera is compared to Sony-6mm camera.

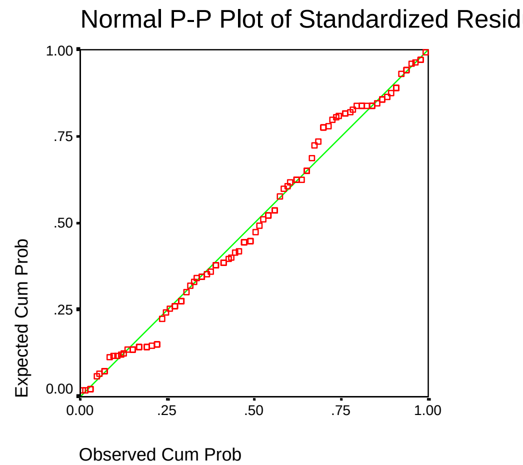

Figure 7: Normal Probability Plot

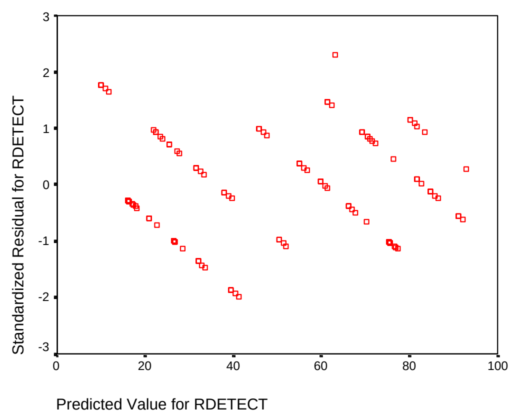

Fig. 8: Standardized Residuals vs. Predicted Value

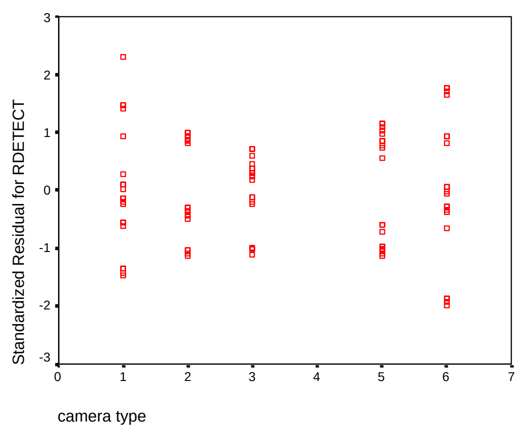

Fig. 9: Standardized Residuals vs. Camera Type

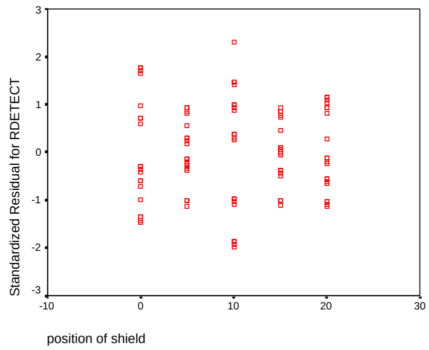

Fig. 10: Standardized Residuals vs. Shield Position

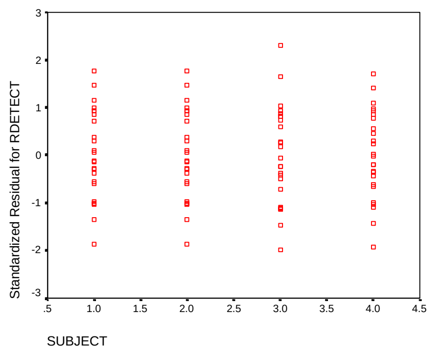

Fig. 11: Standardized Residuals vs. Subject

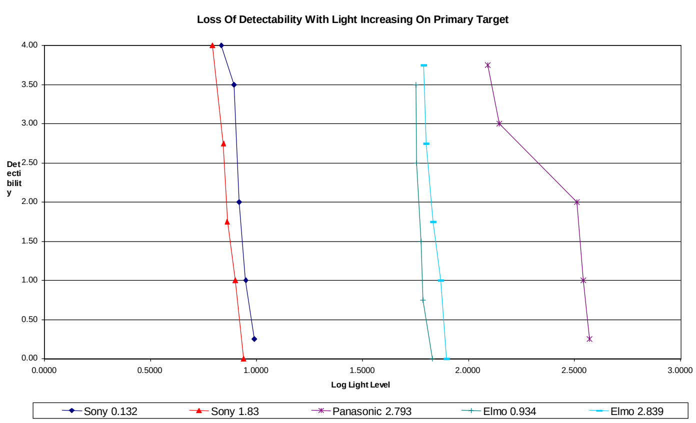

Fig 12: Detectability Loss with Increasing Light on Primary Target

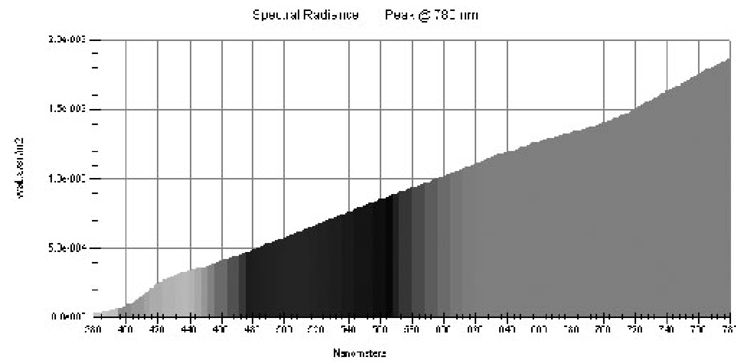

Fig. 13: Spectrum of Incident Light on Target

4. Conclusions

The authors have described an experimental procedure to characterize the gain ability of video cameras for use in automotive and military conditions The Sony camera was found to have the highest ranking in the detectability test. The method the authors describe can determine which camera will perform the best under illumination conditions that span several orders of magnitude. Future work will involve using new "high-dynamic range" cameras as well as measuring the time-response of the cameras, as it takes a finite time for the cameras to adjust after the introduction of a new "high-glare" source.

References

[1] Y.Pecht, "Wide Dynamic-range cameras", Opt. Eng. Vol. 38,(10) pp. 1650-1660, 1999.

[2] A.J.P. Theuwissen, *Solid State Imaging with Charge Coupled Devices*, Kuwar Academic, 1995.

Appendix
Table 7
Camera data from Experiment 2

camera type	sony-6mm				Panasonic		Elmo			
LHS luminance (cd/m2)	0.132		1.83		2.793		0.9336		2.839	
log (lum)	-0.879426		0.2624511		0.4460709		-0.029839157		0.453165393	
	log(LUM)	avg resp	log(LUM)	avg resp	log(LUM)	avg resp	log(LUM)	avg resp	log(LUM)	avg resp
Initial	-0.9578	4.00	0.2428	4.00	0.4150	3.75	-0.0060	4.00	0.4853	4.00
A	0.8349	4.00	0.7922	4.00	2.0913	3.75	1.7508	3.50	1.7874	3.75
B	0.8935	3.50	0.8439	2.75	2.1443	3.00	1.7550	2.50	1.8004	2.75
C	0.9182	2.00	0.8624	1.75	2.5113	2.00	1.7748	1.50	1.8321	1.75
D	0.9492	1.00	0.8993	1.00	2.5412	1.00	1.7858	0.75	1.8675	1.00
E	0.9899	0.25	0.9388	0.00	2.5707	0.25	1.8309	0.00	1.8963	0.00

Presented and published in the Proceedings of the IEEE 2001 Intelligent Vehicles Symposium held at the National Institute of Informatics, Tokyo, Japan.